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PART I.

LIGHT FROM A PIN-HOLE;

COMPREHENDING VISUAL ANGLE

AND

THE MICROSCOPIC POWER OF THE EYE.

BY

JOHN GORHAM M.R.C.S.E., L.S.A., M.S.A., &c.

FELLOW OF THE PHYSICAL SOCIETY OF GUY'S HOSPITAL.

Reprinted from the "Quarterly Journal of Microscopical Science."

Illustrations on Wood and Chromo-Lithography.

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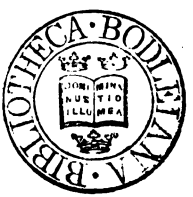

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INTRODUCTION.

THE present Paper forms the first of a series on the same subject now being published, through the kindness of the Editors, in the *Quarterly Journal of Microscopical Science*. It purposes to show that when pencils of light, which are disposed in a particular manner, have a defined magnitude, occupy a certain position before the eye, and are of small intensity, are caused to fall on certain bodies, these can be distinguished at distances from the eye much shorter than those which have been usually considered compatible with distinct vision; and that when thus examined they are, as might be anticipated from the known properties of the visual angle, much enlarged.

No apology is deemed necessary for thus introducing several new and interesting phenomena resulting from direct experiment, which serve to render the

theory of the "Visual Angle" attractive at the same time that they enable us to demonstrate the microscopic power of the healthy eye. For whether it be required to comprehend the magnifying power of lenses, used either singly or in combination, as in the telescope, microscope, &c., or correctly to understand the theory of vision in the healthy eye, or to be conversant with the fundamental principles of perspective, it is alike important to become acquainted with the properties of the visual angle.

Tunbridge, Kent,
October 1, 1854.

On the Magnifying Power *of* Short Spaces, *illustrated by the transmission of Light through minute Apertures.*

By John Gorham, M.R.C.S.L., Memb. Soc. Arts, &c.

In the present communication it is my intention to furnish a few phenomena, illustrative of *visual angle*, of the *magnifying power of short spaces intervening between the eye and the object*, and of the *inversion* and *multiplication of images by the simple transmission of light, without refraction, through small apertures in plane surfaces.* As these illustrations are somewhat novel, I hope they may prove interesting to the readers of the 'Microscopic Journal.'

The apparent enlargement of minute objects held and examined at very short distances from the eye, has received less attention at the hands of the writers on optics, than has the minifying power of longer spaces with respect to greater objects. We are more conversant, for instance, with the appearance of a church, or a tree, at one mile, than of a pin's head at one inch; and, at these respective distances, we are more surprised to find the image of the latter enormously enlarged, than that of the former proportionally diminished, forgetting that the very same law is in operation in both instances.

This comparative indifference with respect to the examination of minute objects has arisen, doubtless, partly from their very insignificance, as we are accustomed, though not always justly, especially when examining those minute portions of the handiwork of God which bear upon them, without and within, the impress of the "hiding of his power,"* to consider little things contemptible, and beneath our notice; partly, again, from the fact of our being able to avail ourselves of the assistance which a lens made of glass affords, whenever we wish to examine any small body; and especially from the recollection that at any distance less than six inches, which is usually considered the shortest limit for distinct vision, a feeling of distress has always accompanied the attempt to distinguish the object, whilst at longer distances, the exertion is not only easy but pleasurable. In the former

* Habakkuk iii. 4.

case, too, as we shall have occasion to show, certain artificial contrivances are necessary to ensure vision at all, whilst, in the latter, the adjustment of the eye is without effort, and requires no adventitious aid.

Whilst the transmission of light through small apertures, in the way hereafter to be explained, serves to show, in a conclusive and striking manner, that apparent enlargement of objects which accompanies their diminished distance from the eye; the variation in the size of the images at different ages, and in different eyes at the same age, and which is found to be very considerable, may, possibly, at some future time, assist in determining the relative refractive powers of the transparent media of the eye; and hence may come to prove of utility in the diagnosis of disease, although it is not my intention to insist upon the application of the phenomena elicited by these experiments, either to the one or to the other of the above important uses, in this present communication.

For the few preliminary remarks about to be offered, some apology might be necessary, were it not that a difficulty seemed inevitably to connect itself with any attempt at arranging the subsequent portions without them. These remarks will be found, indeed, to consist of a mere repetition of those principles in optics, which, to a certain extent, and in particular aspects, have received abundant illustration from experiments, to prove their correctness, and make them intelligible; and which, nevertheless, in other aspects, are calculated to afford new and important results,—for the laws of nature, so far from becoming deteriorated by a scrutinizing examination, always derive additional confirmation from the process. The *visual angle*, for instance, when applied to the investigation of objects at distances beyond ten inches from the eye, defines and measures the sizes of their images as depicted on the retina; and, when applied to the imitation of such images by delineating them on a vertical plane, it explains the art of perspective; and these are such familiar examples of the application of a general law as scarcely to require specifying. But, on the other hand, if the magnitude of the visual angle is inversely as the distance, the size of the object remaining the same; if bodies really do appear larger when brought very near to the eye, as we know they appear smaller when more remote; if, in short, the law of visual angle holds good for all distances, for the small as well as the great, it may be worth inquiring as to the kinds of pictures which are formed on the retina, when exceedingly small objects are held very near to the eye, so near, indeed, as to exceed the limits of distinct vision. That such objects present

wondrously magnified images, if discerned at all, is evident. This, therefore, is just that kind of inquiry which, from having been instituted in comparatively a few cases only, serves to elicit new phenomena, of which it will be one of the objects of this paper to furnish a few illustrations.

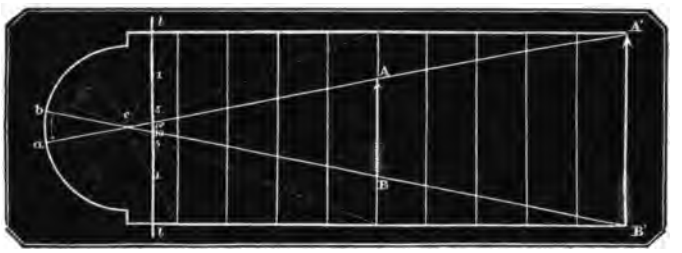
That the *apparent* size of objects depends on their distance from the eye may be shown, with respect to short distances, by the following simple experiments:—Having closed an eye, place the forefinger of one hand across the palm of the other, and both at arm's length. Now gradually bring the finger towards the open eye, and its image will be gradually and yet sensibly magnified; and when the finger is about midway between the hand and the eye, its apparent size will be doubled. If a watch be used instead of the finger, the enlargement of its image will be very evident, and the palm of the hand which remains stationary will soon be completely hid by the apparent expansion of the watch. Whilst experiments of this, and of a like nature are, in themselves, of easy performance, and require no costly apparatus, yet they are not to be supposed the less useful on this account, although, there is reason to fear, this is too often the case; as if the mind were incapable of receiving any idea of the science of optics, excepting through the medium of finely-ground lenses set in burnished brass and polished mahogany. We are delighted, on the contrary, to discover the elements and exponents of general laws, themselves of the greatest importance, in combinations of such homeliness and simplicity.

Take a couple of cards, the one four times as large as the other, that is, twice as long and twice as broad; a card from a pack and the cover of a book will answer the purpose. Let the experiment be conducted as the preceding one, the small card being substituted for the finger, and the book-cover for the hand. Then, not forgetting to keep one eye closed, when the former is advanced to a station midway between the latter and the eye, both will *appear* exactly of the same size; in other words, the images of both will, as regards magnitude, be identical. Hence it appears that the linear magnitude varies inversely as the *distance*, and the superficial extent, or area, varies inversely as the square of the distance, for the finger was *twice* the length, and the small card *four* times the area, at half the distance.

The explanation of this law is founded on the properties of the *visual angle*. Let AC, BC, fig. 1, be rays from the extreme point of the arrow AB, which cross within the eye somewhere about its centre at C; then the angle ACB is termed the visual angle. A glance at the figure shows that

the greater the divergence of the lines composing that angle,

Fig 1.



the greater will be the arc on the retina occupied by the image *a b;* and, also, the greater that image, the greater will be the angle included by the lines AC, BC, the lines of visible direction. for the angle *a* C *b* is always equal to the angle ACB. The visual angle varies exactly as the arc of the image, and as that angle may be formed with sufficient accuracy by drawing lines from the centre of the eye to the extremities or boundaries of an object, it affords a convenient expression of the length or size of the image. If a second arrow, A'B, twice as long as AB, be placed parallel to AB, and at double its distance from the centre of the eye, then, by the properties of similar triangles, their visual angle will be equal, and their apparent magnitude identical. Conversely, if the two arrows be parallel, have the same visual angle, or apparent magnitude, and one be twice as distant as the other, the more remote one must be twice as long as the other. The apparent magnitude of the *same* object, at different distances, may be inferred on the same principles. Thus, if AB approach the eye, remaining upright all the time, the visual angle will enlarge, and, at half its length, will appear double; or, if AB recede from the eye, it will be seen under a smaller angle, and appear proportionally smaller,—in fact, the apparent length of an object increases in the same ratio as its distance from the point C, within the eye, decreases. Hence, to bring an object near the eye is to magnify its image.

The degrees of divergence, or convergence, of the visual angle for smaller and larger distances of the object may be well shown by substituting black threads for the lines composing the angle. These threads may be attached to the extremities of the arrow, which should be made of wood, as well as the plane on which it is intended to slide to and fro. Ten vertical lines may be drawn on the plane, dividing any given interval between the arrow and the eye into ten equal parts, which we will suppose to be inches. When the threads

emanating from the arrow A'B', fig. 1, are drawn through a hole bored at C, the arrow can be moved to and fro, at pleasure, by traction at the knot from behind, and thus the gathering and spreading of the rays of the visual angle are well imitated. When the arrow is brought near to the eye the threads are seen to diverge rapidly from C, and when it is removed to a greater distance they are brought nearer together. During the passage of the rays toward C, they may be supposed to be transmitted through a plane of glass, *l l*, held vertically before the eye, and on which the varying lengths of the image of the arrow, at different distances, may be measured. In this way it will be seen that, at ten inches, the space included by the visual rays (10 to 10), when they cut the plane of glass is very small, and this may be regarded as unit. At five inches (5 to 5), the space is exactly doubled, indicating that the image is twice as large at half the distance. At one inch the image is ten times as large, for the interval from 1 to 1 is ten times as great as the interval from 10 to 10. In all these cases the relative magnitude of the image, compared with its size when the object is ten inches distant, is found by dividing the distance for distinct vision of any object, and which is assumed to be about ten inches, by the new and shorter interval, produced at pleasure, by holding the object very near to the eye. Hence:—

At 10 inches the image will be $= \frac{0}{10} = 1$

„ 9 „ „ $= \frac{10}{9} = 1\frac{1}{9}$

„ 8 „ „ $= \frac{10}{8} = 1\frac{1}{4}$

„ 7 „ „ $= \frac{10}{7} = 1\frac{3}{7}$

„ 6 „ „ $= \frac{10}{6} = 1\frac{2}{3}$

„ 5 „ „ $= \frac{10}{5} = 2$

„ 4 „ „ $= \frac{10}{4} = 2\frac{1}{2}$

„ 3 „ „ $= \frac{10}{3} = 3\frac{1}{3}$

„ 2 „ „ $= \frac{10}{2} = 5$

„ 1 „ „ $= \frac{10}{1} = 10$

„ $\frac{1}{2}$ „ „ $= \frac{10}{\frac{1}{2}} = 20$

At $\frac{1}{4}$ inch the image will be $= \frac{10}{\frac{1}{4}} = 40$

„ $\frac{1}{8}$ „ „ $= \frac{10}{\frac{1}{8}} = 80$, &c.

The expression "to magnify an object," common in optics, is an unhappy, because incorrect, mode of stating the fact, that the *images* formed on the retina of the eye are always magnified, as the distances of the objects by which they are produced are diminished. This should be constantly borne in mind. To say that an object appears larger is merely to refer it, by a mental process, to some imaginary and greater distance at which it looked smaller; and it is said to be *magnified* when it appears greater than it is usually found at those distances, ordinarily considered necessary for distinct vision.

In using a single lens, the magnifying power, resulting from proximity of the object to the eye, and which is independent of the peculiar function of the lens itself, is commonly much underrated. When, for instance, we place an object in the focus of a lens held close to the eye, and having a small focal distance, and find its image magnified by the process, we are apt to merge the whole of these effects in the lens, and in its so-called magnifying power, forgetting the new position of the object, its short distance from the eye, its enlarged visual angle, and the resulting increased magnitude of its image. The magnifying power of a lens is equal to ten inches,* divided by the focal length of the lens. But it is worthy of remark that this is just that power which is possessed by diminished distance, independently of a lens, and is found precisely in the same way; that is to say, by dividing the distance at which we see any small objects most distinctly, by the interval of nearer approximation to the eye. Now a lens of half-an-inch focus is seen to magnify twenty diameters, for $\frac{10}{\frac{1}{2}} = 20$; but it has been shown, by the properties of the visual angle, that the apparent dimensions of any small object placed at the same distance are identical. Hence the difference between the magnifying power of a single lens, used as such, and the magnifying power of a short interval between the eye and the object, is equal to 0; in other words, a lens would appear to accomplish nothing more, magnitude alone considered, than proximity, aided by the refraction of the humours of the eye, can effect.

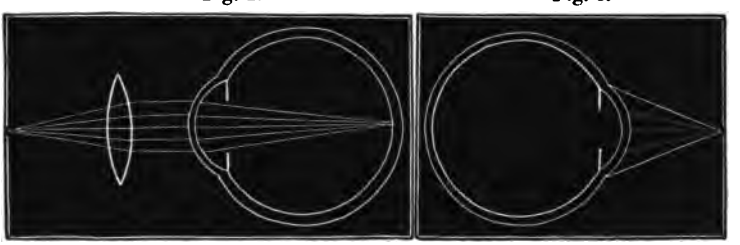
In giving such prominence to the powers of unaided vision,

* This is stated differently by authors; some supposing the shortest limit for distinct vision equal to ten inches, others to five.

it must, however, be conceded that, in using a lens, the divergent rays are made parallel, and are thus prepared to enter the eye, and produce distinct vision. The outermost rays, too, those especially which are spread beyond an angle of 48°, would be reflected from the surface of the cornea, and altogether lost, and with them, a large quantity of light, otherwise appropriated to the illumination of the object, would disappear, were a lens dispensed with. Hence a lens of glass is useful in rendering parallel the rays which emerge from it after refraction (see fig. 2); and it is more especially necessary, in gathering the most divergent rays, and thus bringing out the magnified image more distinctly by the larger quantity of light received from the object.

These remarks are not at all likely to have any effect in deteriorating the value of such a useful optical instrument as the double convex lens, the utility of which, in some form or other, everybody acknowledges. They are made the rather to bring out by contrast the remarkable fact of the increase, which may be observed in the size of those images which are formed, by examining objects at very short intervals *without* a lens. A subject which is inviting, comparatively unexplored, and doubtless worthy the attention of those engaged in optical science.

Fig. 2. Fig. 3.



It is supposed that those rays only which fall within an angle of 48°, or thereabouts, measured on the surface of the cornea, pass through it, and are refracted in their passage (see fig. 3). Those which are not included within this angle are reflected by the verge of the cornea and the sclerotic coat. Rays in rapid divergence, however, may enter the eye, provided the point from which they emanate be very near or close to it. There is, probably, no easier method of proving this than by tracing the course of the rays of light which are transmitted through small apertures of known dimensions, through the humours of the eye to their final destination on the retina. For when the size of any object and its distance from the eye

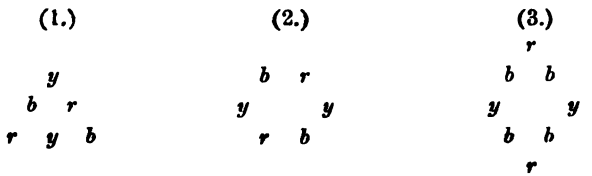
are known, the visual angle is also known, and hence the magnitude of the image formed on the retina is easily discovered. But these small apertures may be held in any position, either near to, or remote from, the eye; and thus the magnifying power of short spaces is seen to be capable of easy demonstration.

This is shown in the following curious, and, as far as I am aware, previously unnoticed phenomena, which are based upon the transmission of light through small apertures.

In order to exemplify this subject, let a number of common pill-boxes be procured, about half an inch in depth and one inch in diameter;* and let small holes about the 1-40th of an inch in diameter, and at regular intervals of the 1-10th of an inch, be punctured through the bottom with a needle;† as in Plate VIII., fig. 1.

These apertures are best made by carrying the needle from without to within, to prevent their size and shape being afterwards altered by friction. Then let small pieces of tracing paper be stuck over them with gum water, to prevent too much light entering the eye. For this, by contracting the pupil, would diminish the size of the image. Their translucency may be still further slightly diminished by communicating a tint with water colours, and for this purpose the three primary colours, *red*, *yellow*, and *blue*, may be used, for reasons hereafter to be specified.

Combinations of these perforations related to the square, the pentagon, or the hexagon, may be left to the ingenuity of the reader. A few, partaking of the latter form, are subjoined; wherein the letters *r*, *y*, *b*, and *w*, refer respectively to the colours red, yellow, blue, and white. It may be premised that the tints should be laid on, as in ordinary tinting, coat after coat, until they become brilliant, without being at the same time opaque.



* The size marked two drachms used by chemists and apothecaries.

† Sewing needles are generally sold in papers, which are numbered from one to twelve, according to their thickness. With a micrometer under a microscope, I examined the diameter of apertures made with needles from the papers marked Nos. 6, 7, 8, 9, and 10, and found them respectively equal to the 1-36th, the 1-38th, the 1-44th, the 1-50th, and the 1-70th of an inch.

(4.)

b w r
w y b w
y r w r y
w b y w
r w b

(5.)

b
b r y b
y r
b r y b
b

(6.)

r y r
b w b w
r y r y r
w b w b
r y r

To these combinations we shall have occasion hereafter to refer.

Now, if distance produced no change in the apparent magnitude of objects, the apertures should remain as needle holes; and the colours should appear red, yellow, and blue, at all distances. But this is not found to be the case. On the contrary, when examined by looking through the bottom of the box from the inside, they are found to present the following phenomena:—

1. Bringing the box within an inch or two from the eye these small inlets appear to expand into circular discs, which touch one another at their margins (see Plate VIII. fig. 2). And when held still nearer to the eye they become so much enlarged as to overlap at their edges (Pl. VIII. fig. 3). But if the discs overlap, the colours must blend; and it is worthy of especial notice that this is actually found to take place. For when the three primary colours, red, yellow, and blue, are thus united in pairs, the secondary tints, *orange*, *green*, and *violet* are produced; and when the three primary tints all combine there is formed *white* light (Pl. VIII. fig. 3).

These effects are demonstrable, and the colours are sufficiently distinct by the light of a taper held a few inches from the eye; but they are more brilliant and beautiful when seen in a room screened from the direct rays of the noonday sun by an ordinary white blind

2. Assuming each of these apertures to be an object, the circular disc is its enlarged image painted on the retina of the eye. It is difficult to obtain a correct idea of the size of these images without actually measuring them; inasmuch as this is estimated very differently by different individuals. To some, for instance, they appear to exceed an inch in diameter; to others they are as small as a fourpenny piece or a split-pea. My own imagination presents them as exactly resembling small coloured wafers. But it is probable that a cognizance of the actual size of the apertures themselves being associated with the perception of the image leads to an erroneous conclusion as to their real dimensions. In every instance, how-

ever, the magnitude assigned to them has been less, and never greater, than their true size.

In order to measure them it is merely necessary to compare them, that is, the images, when the apertures are held at half an inch from the eye, with circles, or diameters of circles, of known dimensions, placed at ten inches. This is effected in a rough way by holding a measure horizontally ten inches from the eye, and noticing, when this is examined by looking through the aperture, how many inches or parts of an inch are included within the area of the circular image. When used for this purpose the apertures should not be covered with tracing paper, and the kind of light used should be specified.

Now, by the properties of the visual angle it may be shown that when a small round opening, the 1-40th of an inch in diameter, or thereabouts, is held at ten inches from the eye, it presents an image equal to about the 400th of an inch across, and which appears as a mere speck. But when this same opening, or aperture, is examined at half an inch only, its image will be found so much enlarged as to cover a circular area two inches and a half in diameter, placed, in order to institute the comparison, at ten inches from the eye; and this may be easily proved by direct experiment. The apparent size of the disc has therefore undergone an immense increase by this simple process of bringing the aperture nearer to the eye. It is, in fact, magnified a thousand diameters. For—

$$\tfrac{1}{400} \text{ inch} : 2\tfrac{1}{2} \text{ inches} :: 1 : 1000.$$

But this gives the rate of increase in one dimension only. Hence, if our calculations are carried a little further, we shall find the entire area of the disc magnified one million times. For:—

Area of circular disc (α) $2\frac{1}{2}$ inches in diameter = 4·90873

" " (β) $\frac{1}{400}$ " " = ·000004908

Then area of (α) : area of (β) :: (diameter)^2 : (diameter)^2

$$\therefore \frac{\text{area } \alpha}{\text{area } \beta} = \frac{(\frac{5}{2})^2}{(\frac{1}{400})^2} = \frac{25}{4} \times \frac{40000}{1} = 1000000.$$

Thus it appears that the image which is produced by examining a small hole made with a needle is magnified one million times by simply diminishing its distance from ten inches to half an inch from the eye.

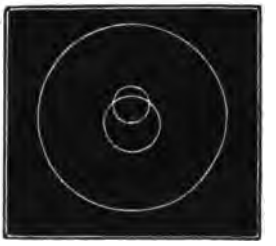
3. These discs are invariably diminished in size when, from any cause, the intensity of the light is increased. While, therefore, on viewing them by the direct rays of the sun, their margins scarcely touch, by diffused daylight, or the light of a taper, they directly overlap. This result is clearly owing to

the alternations of size of the pupillary aperture: for this circular opening expands when the light which enters the eye is diminished, and contracts when the light is increased.* For the same reason the discs always become smaller when the other eye is opened, and again resume their size when it is closed. This effect is instantaneous, and may be repeated again and again, as often as we choose to make the experiment. These rapid alternations of size in the circles, resulting from the alternate contraction and dilatation of the pupil, show, in a striking manner, how the quantity of light which enters the one eye regulates and controls the pupillary aperture of the other, and thus points to the necessity for shading both eyes in those diseases where it is important to exclude the light from either.

4. That the pencils of light emanating from these apertures cross within the eye, come to a focus, and form an inverted image at the bottom, may be inferred from the fact of their visual angle being less than 48° when they are examined at half an inch. And that the image itself is really inverted may be proved by making a second very small aperture close to the edge of the larger one (fig. 4). The image of this double aperture is an ovate disc seen in its true or erect position (fig. 5), in which position it would not be seen were it not inverted on the retina.

Fig. 4.

Fig. 5.



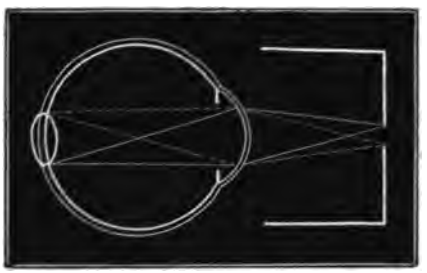
The visual cones emanating from these apertures, therefore are thus disposed (fig. 6) and transmitted through the humours of the eye, by which they are rendered convergent, and so come to a focus at the bottom.

5. It is worthy of notice that the innermost rays of these cones of light, which we have just examined, cross each other almost directly after proceeding from their radiant points towards the eye: and, as they do not again intersect during

* The ordinary dimensions of the opening of the pupil, seen through the cornea, are from the 0·27th to the 0·13th of an inch; and its mean size is the 0·20th of an inch.

their passage through its humours, the image of any small object held within the angle *a c b* should be formed erect on the retina, and should be seen, consequently, in an inverted position.

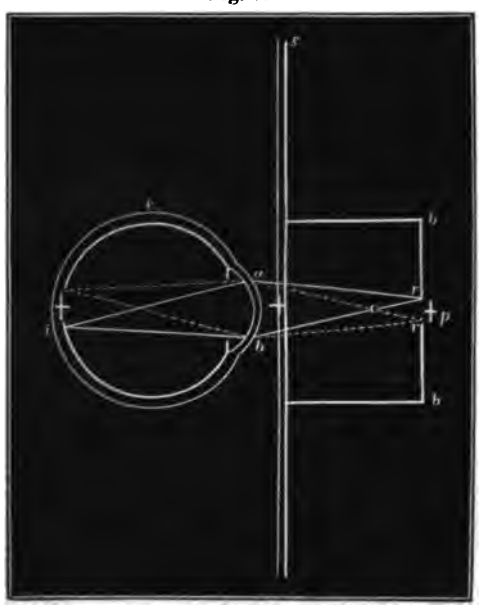
Fig. 6.



That this is the case may be proved by direct experiment. For this purpose I mounted a small cross about the tenth of an inch in length, and the twentieth of an inch broad, cut from a sheet of coloured gelatine, on the centre of a glass slide, with gum water, so that it might be used at pleasure. On holding this small cross between the eye and the aperture a small inverted image of it is seen, as if drawn in the centre of the disc. Moreover I noticed generally, that the images of all objects which were so placed as to subtend the angle *a c b* were seen in an inverted position.

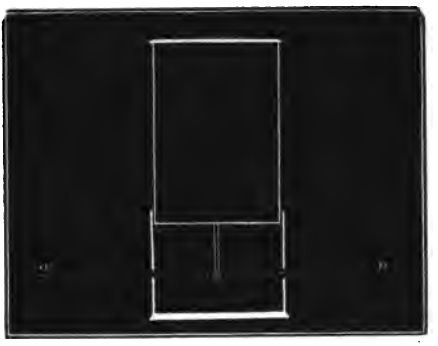
To illustrate this, let *r r* (fig. 7) be the radiant points proceeding from the aperture *p*, in the bottom of the box, *b b*, and let *r a b r' a b* be the cones of light passing through the slide of glass *s* and the eye *e*, to form a circular image on the retina *i*. Let the cross which occupies the centre of the slide be sufficiently small to subtend the angle *a c b*; then the rays of light *c a* and *c b*, which illuminate its extremities, are transmitted to the retina without intersection, forming there an erect image *i*, which is seen in an inverted position at *p*.

Fig. 7.



A rude modification of this experiment may be made with a pin, a cork, and a small pillbox. This latter should have a small hole, about the fortieth of an inch in diameter, made in one of its sides with a needle; and a circular piece, about the eighth of an inch in diameter, should be excised at a point exactly opposite the first from the other side. The pin is now stuck into the cork and the box inverted over it, the centre of each opening and the head of the pin being all in one straight line (fig. 8, *a a*). On looking through the small hole the pin is seen much magnified and in an erect position; but when examined through the larger opening it appears inverted.

Fig. 8.

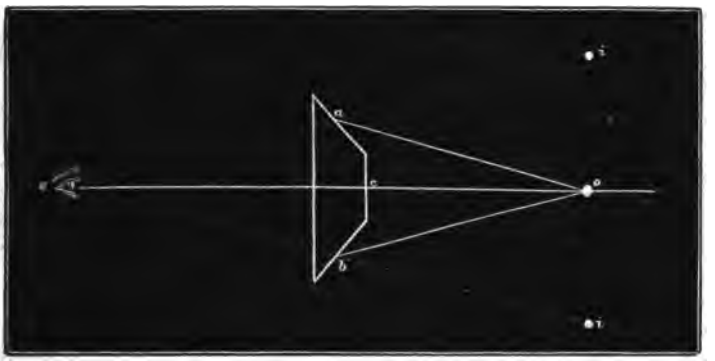


6. In pursuing these investigations it occurred to me that, whilst in the *polyscope*, or *ordinary multiplying glass*, the multiplication of the images is effected by causing the rays which proceed from the object to travel towards the eye in as many different directions as there are images, *by refraction:* the same result might be obtained without a glass, *by transmission.* For it was clear, that if it be possible to view the same object by rays of light, all emanating from different points, and concentrating themselves in the centre of the eye, such an object must appear multiplied. Hence, on examining a small cross, similar to that which was used in the last experiment, under the light admitted through six apertures, by holding it between them and the eye, I was gratified to find my anticipations realized; for six inverted images of the cross immediately appeared: one being painted on the centre of each disc, as if by magic.

This phenomenon was scarcely less interesting than either of the former, for it seemed to present a new and anomalous position of the object, with respect to transparent media, in the formation of multiplying images; in short, a new kind of *polyscope* was discovered, having properties distinct from those belonging to an ordinary multiplying-glass. In order to point out the difference between these two optical instruments, it must be borne in mind that, in a common *multiplying-glass*, the object to be multiplied is placed on one side of the glass, and the eye on the other, while the images are conveyed to the eye by the aid of the refracting power of the glass. Thus, in the

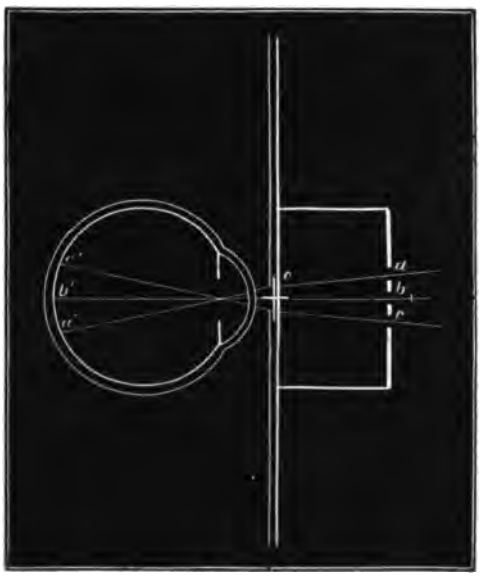
multiplying-glass with three faces, *a b c*, fig. 9, let the object be placed at *o*, and the eye at *e;* then the new images, *e i*, are seen in the direction of the emergent rays, *a e*, *b e*, after refrac-

Fig. 9.



tion; that is to say, the rays *a o*, *b o*, emanating from the object at *o*, converge on the opposite side of the glass, and enter the eye at *e*, which thus perceives three images instead of one: the first being that of the object in its real position, *o*, and the other two in the directions *e i* and *e i*. But the same result may be obtained, as we have said, without refraction,

Fig. 10.



by holding a small object nearly close in front of the eye, and inspecting it by the light transmitted through small apertures, when the number of the images will be found to coincide with that of the apertures, and will be seen in the direction of the pencils of light which travel through them. In order to illustrate this, let *a b c*, fig. 10, be three small apertures, about the 1-40th of an

inch in diameter, and the 1-8th of an inch apart, made in one straight line in the bottom of a pillbox, and let *o* be a small cross of gelatine, as before described, or any other small, transparent, well-defined object mounted on a slip of glass. Let *e* be a section of the eye, and *a' b' c'*, the images painted on the retina: these images will be circular discs, having, in the centre of each, an inverted image of the object *o*, as shown in the following figure (11).

Hence the bottom of the box, which contains these openings *a*, *b*, and *c*, is similar to a multiplying-glass in producing as many images of the object as there are transparent facets in the glass, but unlike in these important particulars, that those facets are all in the same plane; that the light is not refracted by them, but merely transmitted; and that the eye and the object are both on the same side, that is, in front, of the multiplying medium.

In this experiment it may be instructive to notice: I. The rectilineal direction of the visual cones in their passage from the apertures to the eye, each of which, although intersecting the others, and being crossed by them again and again, travels in one undeviating course, until it falls upon the cornea, and is finally brought to a focus on the retina, thus defining the *shape of the images*. 2. The last direction of the pencils of light which fall upon the cornea, determining the *position* of the images in space, for an object always appears in the direction in which the *last* ray of light comes to the eye. If the light which comes from a star were bent into fifty directions before it reached the eye, the star would, nevertheless, appear in the line described by the ray nearest the eye. 3. The influence of proximity of the object to the eye in increasing the *magnitude* of the image. 4. The perception of many images, of only one object, that object being rendered visible not by one pencil of light only, but by many pencils in different directions, explaining the cause of the *multiplication* of images; and 5. The peculiar arrangement and disposal of the rays, during their passage from the apertures to the eye, in producing an *erect retinal image*, and an *inverted mental one*:—for these are so many phenomena, each and all of which serve to show how the laws of light may be illustrated by means the most simple.

7. The multiplication of images, referred to in the last paragraph, has been shown to result from the simple transmission of light through small apertures. But there is a second case to be noticed, wherein double images are produced by refraction, that is, refraction during the passage of the rays through the eye, and without the intervention of a lens of any kind.

These double images are seen on holding a small object *behind*, instead of in front of, the apertures; and when seen, it is to

Fig. 11.

Fig. 12.

be noticed that they always occupy that oval space formed by the mutual intersection of the circular discs, fig. 12, *s*.

In order to explain this, let two small holes (*a a*, fig. 13) the 1-70th of an inch in diameter,* and the 1-20th of an inch apart, be made in the bottom of a box, and let a pin, *p*, be held behind the box, at the distance of an inch or two. On looking at this through the apertures, a double image of it will be seen at *i i*. When the pin is withdrawn to a considerable yet certain distance, say *p'*, a single image only will be noticed, the rays coming to a focus at *f*; but on bringing it nearer, the two again become visible. It is evident that these phenomena are to be referred to the refraction of light, during its transmission through the humours of the eye.

Fig. 13.

The refracting power of the eye varies at different ages, and in different individuals of the same age; and it would appear that its intensity may be measured by ascertaining the distance at which any small object, such as a pin, produces a single image, when viewed through two apertures, in the manner just described; for when the distance is known, the direction of the rays being determined by the interval of the apertures, the visual angle is also known; and when one image only is seen, the rays by which it is formed are brought to a focus exactly at the bottom of the eye, thus measuring the refractive power of its humours.

* Such apertures can be made with a needle marked No. 10.

But if the same object, at precisely the same distance, were examined by another eye, and if two images were seen instead of a single image, there is good reason to infer that, in the latter case, the transparent media of the eye would be endowed with powers of refraction greater than in the former; hence the relative refracting power of two eyes may be found by measuring the intermediate space between two points, say p and p', at which the same object appears as one, that is, forms a single image in two different individuals.

I have, in this paper, laid before my readers an account of several new phenomena which have occurred to me whilst investigating some of the laws of optics; in doing which it accorded with my design and professional avocations to be brief and perspicuous, rather than to write an elaborate essay. On a careful perusal, especially of the sixth paragraph, it will, doubtless, not have escaped notice, that certain of the results involve principles bearing a direct application to the construction of one or two amusing and instructive optical instruments, not heretofore invented. But I shall beg to reserve a more particular description of these for a second paper.

It has been before noticed that less attention has been bestowed upon the investigation of objects that lie near at hand, within an inch or two, we will suppose, of the eye, than upon objects which are placed at a considerable distance from it, that, for example, of as many furlongs. I have also endeavoured to show that small circular perforations made in a card and rendered semitransparent, constituted in themselves objects well adapted to illustrate the magnifying power of short spaces, by presenting a rapid and palpable enlargement of the visual angle to the eye; and lastly a series of phenomena has been described, which resulted from viewing small figures held close to the eye *in front of* such apertures, and rendered visible by the light admitted through them.

The whole subject arranges itself therefore under two distinct divisions, which comprise:—1. An examination of the images formed by viewing objects held *in front of* small apertures; and 2. An examination of those images which result from placing the objects *behind* the apertures.

1. Of images formed when the eye and the object are both on the same side, that is, in front of the apertures.

We have already seen that when bodies not exceeding the diameter of the pupillary opening of the eye are held in close proximity to the visual organ, and are then examined by the light admitted through small inlets about the fortieth of an inch in diameter, their images become *magnified*, *multiplied*, and *inverted;* and further, that they are illuminated with light

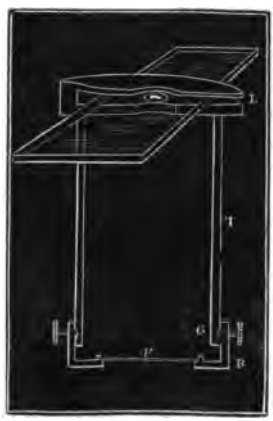
of an intensity varying with the number of apertures employed to render them visible.

This light, be it observed, is always simply transmitted; never being reflected nor refracted by the intervention of glass, or of any other substance having catoptric or dioptric effects. The apparatus required in these experiments therefore is essentially very simple and uncomplicated, consisting indeed of a mere short tube open at one end, and having a plane, perforated with small holes to admit the light, at the other; while the object to be examined is applied at the open end, and held as close to the eye as possible. Hence a pill-box and a narrow slip of glass constitute all that is really necessary to explain the laws which are in operation, and to give an idea of the phenomena which are involved in their successful application.

From the remarks made in a previous section it is obvious that these phenomena are owing to the *size*, and to the *intervals* of the apertures themselves, and to their *distance* with respect to the eye. Thus their size should be the one-fortieth of an inch,—their intervals the one-tenth of an inch,—and their distance from the eye from one to two inches. If these conditions are not fulfilled the images become either undefined or dimly illuminated; but when they are strictly observed, the combinations, which an instrument constructed upon such principles is capable of presenting to the eye, are very beautiful.

But a mere tube of pasteboard, however well it might answer for a first experiment, is inefficient, for it is difficult to retain the slip of glass in its proper position between the tube and the eye. It was essential therefore to construct a small instrument of some more solid and durable material, such as wood or ivory, with which experiments might be conveniently performed.

Fig. 14.



This instrument consists of a tube, T, one or two inches long, and about one inch thick, expanding at the end to which the eye is applied into a circular lip, L, which is about one inch and a half in diameter, while that of the round opening in its centre is about half an inch. This end is provided with a slit sufficiently large to permit a thin narrow slip of glass, about an inch broad, to slide easily through it, as shown in the figure. The other end has a circular rim, R,

which revolves in the groove, G, and to this rim is attached a second rim, *r*, which is provided with a female screw, and this secures any circular plane of apertures, *p*, we may choose to insert, at the same time that it admits of its revolution.

A series of objects, either painted or mounted on glass slides, can thus be examined at one end by the light admitted through perforated planes at the other. As such an optical contrivance is a mere conductor of the light directly from the apertures to the eye, while at the same time it excludes all the extraneous rays, it may not inaptly and for convenience sake be denominated a *diascope:* a term derived from the two Greek words, δια, through, and σκοπεω, I view. And when it is used for the purpose of multiplying images, it may be called the *multiplying diascope.*

The circular planes containing the apertures are made of thick pasteboard, perforated with a needle at intervals of the one-tenth of an inch as before stated; and the openings may be arranged in a variety of combinations, as shown in the patterns from one to six, page 225, of the last paper.

Here let us notice that the round form of the images, depicted on the retina when examining small apertures in this way, is determined by the shape of the pupillary opening of the eye rather than by that of the apertures themselves. Hence it is always circular whether these be *round*, *triangular*, *square*, or altogether *irregular* in outline. This can easily be proved by perforating cards with triangular or square needles. The openings thus made when brought very near to the eye always appear circular. A little reflection will show that this is a necessary result, inasmuch as the outermost rays of the rapidly-diverging cones are intercepted by the *iris*, while the more internal rays pass on through the pupil, thus receiving their circular form.

Hence if the pupil be widely expanded the discs will be large, and *viceversâ*, but nevertheless always perfectly round.

Let us now take a circular plane, presenting a combination of perforations arranged as to colour and relative position as in the outline, No. 4, page 225, of the last paper; and let us notice what kinds of images are presented to the eye when small bodies are examined by the light transmitted through them.

Holding the instrument to the eye with a view to examine the apertures, we observe that the smallest particle of dust, or film of mucus, happening to exist on the surface of the transparent cornea, is immediately detected; and although such bodies have no definite shape, they are to be recognised interfering with the transparency of the discs, and forming an

opaque spot or streak which occupies exactly the same position in each. Similar results are obtained if a small dot, no bigger than a pin's head, be made on a slip of glass with Indian ink, and introduced into the eye-piece of the diascope. The dot now appears multiplied, and as many images of it are seen as there are apertures by which it is made visible.

In like manner if a small semicircle be painted on glass, its images will be multiplied, but each image will be seen inverted, and will appear as a black body on an illuminated and coloured ground.

And if a small triangle, or any other figure of definite shape, be cut from a piece of black paper, and if the *opening* thus made be examined in the same way, a number of illuminated and coloured triangles will be seen on a black ground.

It is when transparent figures are made according to this last method that really beautiful combinations may be produced. But here, in order to insure success, it is necessary that the transparent openings should never exceed in size the pupillary aperture of the eye, fig. 15. Hence they should always be made within the limits of a circle, the 0·18 of an inch in diameter, fig. 16; this being the mean of the greatest and least

Fig. 15. Fig. 16.

expansion of the pupil. If such transparent figures are made greater than this, the margin of the pupil will obstruct some of the external rays, and the outline of the image will thus be lost or badly defined. If, on the other hand, they are less, the quantity of light admitted into the eye will be too small, and the images but feebly illuminated.

Such openings used as objects are to be considered as little else than artificial pupils, modifying the shape and contracting the size of every cone of light which is admitted into the eye from small apertures.

When one of these transparent openings is held close to the eye, and examined with common diffused light, it becomes altogether invisible; but, when it is viewed by the aid of a pencil of light from a small inlet, its outline is well defined and much magnified; and the disc of the inlet, which would otherwise be circular, is replaced by the pattern we may choose to give to the transparency.

And if the pupil of the eye itself, obliterated, as it often is, from disease, have a small portion excised from it, as in

the operation for artificial pupil, the newly-formed opening will appear inverted and multiplied in the same way; and each image, instead of being circular as it is in the healthy eye, will be seen to resemble the figure of the new and distorted pupil.

But in order to demonstrate the images which this instrument is capable of presenting to the eye in the most satisfactory manner; instead of cutting holes in pieces of black paper, a series of figures having a transparent body and a black outline may be painted on glass with Indian ink. For this purpose round patches of ink, about the size of a fourpenny piece, should be laid on the centre of each glass slip with a camel's-hair pencil; and, when dry, transparent figures of the required shape and dimensions can easily be made by erasing a portion of the ink with a finely-pointed and slightly-moistened wooden style.

The forms of such transparencies will suggest themselves to the ingenuity of the reader, but a few are subjoined by way of example (figs. 18 to 33).

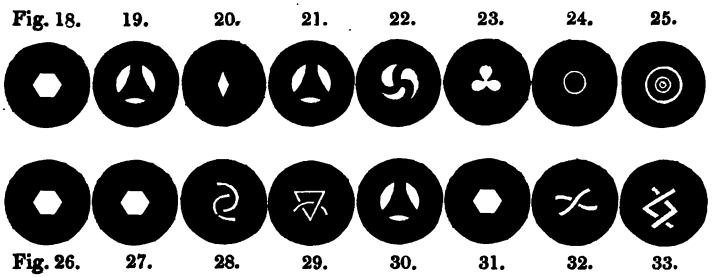


Fig. 18. Regular hexagon.
„ 19. Hexagonal star.
„ 20. Rhomb of 60°.
„ 21. Curved triangle.
„ 22. Ditto.
„ 23. Trefoil.
„ 24. Circle.
„ 25. Concentric circles.
„ 26. Triradiate star of 120°.
„ 27. Straight lines intersecting at 60°.
Fig. 28. Two semicircles.
„ 29. Triangle and semicircle.
„ 30. Curved and straight lines intersecting at 60°.
„ 31. Three lines intersecting at 60°.
„ 32. Two curved lines intersecting at 60°.
„ 33. Two angles of 60° intersecting.

Such forms arrange themselves into two groups; those, for instance, which are entire in themselves, and which constitute elegant designs by their *multiplication* and the shifting of their relative position (figs. 18 to 25), and those again which are imperfect figures, but which produce entire compositions of great beauty by their *combination* (figs. 26 to 33).

As the apertures are arranged in lines which cross each other at angles of 60 and 120°, the outlines of the transparent figures should bear the same angular relation. Thus the modifications of the equilateral triangle, the rhomb of 60° and 120°, and the regular hexagon, a few of which are given in the above examples, are well suited for the purpose.

When a transparent hexagonal star (fig. 19), slid into the eye-piece of the instrument and brought close to the eye, is examined by the light admitted through a combination of apertures, that, for instance, marked No. 4, at the 225th page, placed at the other end, the images of a number of stars are apparent. These stars are seen to change their relative position with every movement, however slight, of the revolving plane. Sometimes they are observed to touch each other by one ray, at others by two, while in intermediate positions the rays alternate. The patterns which are thus formed are as variable as the parts into which a circle can be divided. They are shown in two of their phases of revolution in the 4th and 5th figures of Plate VIII.

The concentric circles, fig. 25, thus multiplied display themselves with good effect. Their appearance is represented in the 6th figure of Plate VIII., which is produced by using the arrangement of apertures marked No. 5, page 225.

But the combinations effected by the mutual coalescence of the images of the imperfect figures into one entire composite form are the most curious. Thus if the three-rayed star, fig. 26, be examined, its images will be seen either to alternate, or to resolve into one hexagonal reticulation with a dot in the centre of each mesh, as shown in the Plate. And the images of the figure, composed of the straight and curved lines, fig. 30, unite into many fresh devices; two of which are copied in the figures of the Plate.

But it is needless to multiply examples, as those which have been already given will doubtless have sufficed to explain the construction of the instrument, and one of the purposes at least to which it may be legitimately applied.

Hitherto we have confined our attention chiefly to the *multiplication* of the images of *artificial* objects prepared expressly for the purpose, and viewed by the aid of the light admitted through small apertures.

We are now to consider how the images of *natural* objects are *magnified* by the same means

Here let us notice, *in limine*, that we are not about to institute a comparison between two optical instruments, the eye and the achromatic microscope, which although they are constructed on the same principles are yet totally different as to

their uses. The healthy visual organ, itself a perfect instrument, "converses with its objects" at almost all distances, and assists the other senses in becoming acquainted with the form, position, and magnitude of material substances. The microscope, on the other hand, all but a perfect instrument, enables us to see clearly and to examine certain objects, which from their small size and without its aid would be indistinct, if not altogether invisible. It is restricted to the small size and the short distance of its objects, and from its very construction it has magnifying powers which the eye neither possesses nor requires. If the eye were endowed with these, therefore, to the exclusion of its self-adjusting properties, whereby it discerns common objects in the ordinary way at great and small distances, it would be rendered comparatively useless as a visual organ.

Hence it were folly to attempt to invest this organ with functions, the possession of which would subject its owner to the greatest inconvenience. An exemplification of this position occurs to me in the case of short-sighted persons.

When therefore we find ourselves enabled by a carefully-devised experiment to detect, with the naked eye, certain configurations upon or within an object which, we may suppose, has never before yielded an image at all excepting through the medium of a lens, we are not to imagine that we are thereby infringing on the domains of the microscope, which being constructed for this very purpose would present us, perhaps, with an image ten thousand times as large and distinct. But putting this instrument altogether out of consideration, and throwing aside all extraneous assistance, we are the rather to consider how the eye, which has certain limits to distinct vision for short distances, can yet adjust itself for spaces still smaller, and in so doing become converted into a kind of natural magnifying glass.

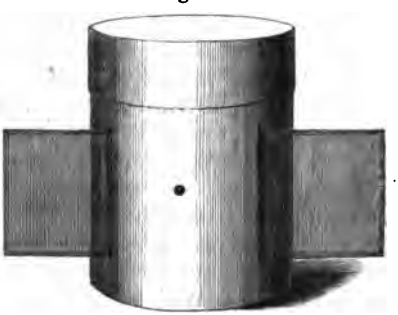
We have now therefore to turn our attention to certain microscopic objects, which are to be examined and resolved without a lens of any description; and we are stimulated to an investigation of this kind by recollecting what has been already attained with respect to the magnitude of the images of small apertures themselves, when placed under circumstances the most favourable for their inspection. Amongst these we cannot fail to have noticed at least two conditions necessary to be fulfilled in such investigations, viz.—First, that the object be held very near to the eye; and secondly, that every ray of light, excepting what is required to illuminate the object, be carefully excluded. The first insures an enlarged image, whilst the second prevents a too great con-

traction of the pupillary opening. Hence the necessity for examining objects through small darkened tubes, and hence, too, the necessity for closing the eye which is not engaged in exploring.

Again, we must not overlook the fact, that in using a small aperture for the purpose of examining any transparent substance there are two methods which may be employed. By the one, *the object is viewed through the aperture;* by the other, the *aperture is viewed through the object.* The former has been almost always adopted by the curious, the latter scarcely ever. It is capable, however, as these papers show, of eliciting so many phenomena peculiar to itself, that I am surprised it has not been frequently used, and the results carefully investigated. Each of these plans throws a different picture on the retina of the eye, and of this the transparent animal membrane chosen for the following experiments will afford, when examined in both ways, abundant exemplification.

For the purpose of presenting very small objects, mounted on microscopic slides in the usual way, before the eye at small distances behind a minute aperture, and to exclude the surrounding rays of light, I took an upright box of pasteboard about one inch and a half deep, and one inch and a quarter in diameter, and having cut a couple of slits through one of its sides sufficiently large to admit of a slip of glass an inch broad sliding to and fro, I made two small apertures opposite to each other, the first the one-thirtieth of an inch, and the second the one-quarter of an inch in diameter; and these were so disposed, that when the glass slip with a small object

Fig. 34.



mounted on its centre was introduced through the slits, the two apertures and the object were all in one straight line; while the slide was about a quarter of an inch behind the smaller opening, see fig. 34.

With this simple apparatus I could examine very small transparent objects at pleasure, either by the light of the sun or of a taper. Whilst, however, it has been thought better to notice the dimensions of the apertures, &c., for the convenience of others who might wish to repeat the experiments, it must not, by any means, be supposed that they are the best adapted to insure success, or that better could not be devised.

Having been engaged in the preparation of a series of dissections of the *compound cornea* of the eye in insects, I naturally subjected one of these beautiful objects to the first experiment in my *lens-less microscope*. Here, however, for the information of those who may not be conversant with these objects, or the peculiarities of their structure, it may be remarked that the roundish, prominent, transparent elevations observed, generally one on each side of an insect's head, constitute the membrane in question. This membrane forms at once the defence and the covering to the delicate parts in the interior of the eye, as well as the transparent medium by which the light is admitted into this tiny organ. It is analogous, moreover, to the transparent cornea of the eye in the higher classes of animals in being transparent, composed of several firmly-adhering layers, and forming the outermost of all the coverings of the eye. But it is altogether dissimilar in this respect, that it is found to consist of an immense number of facets or little pieces lying, side by side, like fine mosaic; and which from being of a regular hexagonal shape, and arranged in perfect order, present when examined under the microscope an appearance like a honeycomb. Hence it has received the name of *compound cornea*.

The eye of the large insect, called the dragon-fly, is recommended for a first trial in dissection, because it is not only very large but exceedingly beautiful. The *compound cornea* is at once separated from the rest of the eye with a pair of finely-pointed scissors, and the dark thick pigment which fills the inside is then washed away by soaking in a tumbler of cold water for an hour or two, and then using a camel's-hair pencil. To procure it in a perfectly clean and transparent state, however, it is better to wash and rewash it after maceration for two days in frequently-changed cold water. Then, while still moist, let small circular pieces be excised with a small punch, and pressed immediately between two slips of glass. In a few days they will have become dry and flat, and may then be mounted in what is called the dry way, as if for the microscope.

I wish it was in my power to convey to my readers an idea of the great beauty of one of these specimens; to say nothing

of the wonderful arrangement whereby upwards of twelve thousand planes, each a perfect hexagon, are packed in a bit of membrane scarcely so large as half the little finger nail. "I have often," says the celebrated Leeuwenhoek, "made repeated dissections of the eyes of various kinds of insects, merely on account of the pleasure the contemplating them afforded me."* But few, however, seem inclined to investigate these subjects for themselves, trusting rather to that second-hand kind of knowledge derivable from books. This distaste for exploring the works of nature may possibly, in some instances, commence with the limited resources of the pocket; the very preparation of a microscopic object involving the necessity for a costly instrument wherewith to investigate it. If, however, I shall succeed in pointing out certain beauties peculiar to the compound cornea in the eye of the insect, which may be discovered with the naked eye, and without a microscope, this membrane will have become invested with a new interest, and thus others may be stimulated to a like inquiry. But to return. Having inserted a slide containing a circular section of the eye of the dragon-fly in the box prepared for the purpose, I proceeded to examine it. Recalling to mind, however, that each of the hexagonal facets is barely the six-hundredth of an inch across, and that many hundreds of such facets are contained in the smallest section, it was much to anticipate that such a structure should be resolved by a process so simple; and when on viewing the membrane, by looking at it through the small aperture, while a lighted candle was held nearly close to the larger one, it presented a semi-opaque and altogether homogeneous appearance, I had almost concluded that my efforts were frustrated. To overcome the difficulty was reserved, however, for a future trial. Now if, instead of a candle, a small wax taper be used, and if this be held at the distance of from five to nine feet, rather than close to the large aperture, a beautiful sight presents itself. Instead of the flame of one taper, there are exhibited the miniature images of the flames of many tapers; and these are not only very definite in their outline so as to be immediately identified, but they are arranged at regular intervals. But, what is still more curious, each image, except the central one, is seen to be composed of the colours of the prismatic spectrum,—violet, indigo, blue, green, yellow, orange, and red; of which the extreme tints are so disposed that the blue portion in each image is always nearest to the central or colourless flame, and the red the most remote from it. Hence the blue and the red tints alternate in concentric

* Leeuwenhoek, vol. ii. p. 341.

circles. When the images which are most distinct, for those near the margin look fainter, assume in the aggregate the form of the hexagonal star, which they not unfrequently do, the appearance is striking and uncommon, see the Plate.

The simplicity of the process by which such a spectacle is produced, together with the novelty of the sight itself, did not tend, of course, to diminish the sense of its gorgeousness; and I was delighted to find a natural multiplying glass in a tissue, which had already contributed so much to my admiration and wonder when examined under a compound microscope.

On viewing the sun in the same way each small and perfectly circular image presented the rainbow tints in the same order, as in the Plate, and the multiplied images of the pale moon were scarcely less beautiful.

I may remark, in passing, that the taper flame and the image of the moon were seen through a specimen mounted in Canada balsam; but the rays of the sun were less distressing to the eye when examined through a specimen mounted in the dry way.

Thus, although I had not, in this experiment at least, succeeded in rendering visible a magnified image of each hexagon in outline, which indeed was the object of my research, I had, in effect, resolved the reticulated structure of the membrane; for in this way only could the peculiarities of a multiplying medium have presented themselves. The interval between each image served, moreover, to indicate the apparent enlargement of each facet, and thus to give a notion of the magnifying power of short spaces.

Still bearing in mind the comparatively enormous magnitude imparted to images on bringing the objects which produce them very near to the eye, and recollecting that the image of a mere needle-puncture seen at half an inch is magnified no less than a million times, it was difficult to renounce the idea of the practicability of defining the hexagonal lattice-work of an insect's eye with the naked eye, and without the assistance of a material lens.

In the former attempt the membrane seemed too opaque to disclose its minute internal configuration, a specimen was therefore now mounted in balsam to increase its transparency. This, however, did not succeed; on the contrary, it had become so indistinct that its structure could now be scarcely made out even with a microscope. In order to define the hexagons it was evidently necessary to colour the membrane. A few specimens were macerated, therefore, for four days in a decoction of logwood, and then carefully dried and mounted

in balsam. In this way they were rendered sufficiently diaphanous to transmit a strong light from the sun without injuring the eye, and their reticulations were not obscured

Having prepared the object, it was necessary to decide upon the distance from the eye best suited for examining it; and as the nearest position would insure the largest image, this was accordingly adopted. The mode of illumination also required consideration, in order that the light should be of such intensity as to make the object visible without dazzling or injuring the eye. The quantity of light received by any object is often measured with an instrument invented for the purpose, called a *photometer;* but a box with small apertures pierced through the bottom might be shown to constitute a good and efficient substitute for such an instrument. For it is to be inferred from the remarks contained in the sixth paragraph, that when a small object is examined by the aid of the pencils of light admitted through such apertures, it is illuminated by the sum of their intensities. Hence the quantity of light thrown upon the object will be regulated by the number of the apertures, being very nearly proportional to them: that is to say, the intensity from two apertures will be nearly twice as great as that from one.

By varying the number of apertures, therefore, we can regulate the illumination of the object with the greatest nicety. It follows that there is no better way, perhaps, of exploring minute objects with the naked eye, than by holding them, mounted on a slide of glass, as near to the eye as possible, and examining them by looking at them from the inside of a small box through apertures made in the bottom, and which are covered with tracing-paper, by the aid of a strong light.

And this is effected by using the little instrument, to which I have ventured to give the name of *diascope*.

Thus all the conditions were fulfilled; for, 1, the object was rendered sufficiently transparent to transmit the rays of light freely, and sufficiently opaque to prevent the solar rays dazzling the eye; 2, it was coloured to make all its parts visible; 3, it was brought sufficiently near to the eye to be enormously magnified; and 4, all extraneous rays of light, those which were not immediately concerned in the illumination of the object, were shut out. It remains to be noticed that the experiment was crowned with success; for, on examining the membrane by the direct rays of the noonday sun, the whole of its area appeared reticulated, and several *well-defined hexagons were seen in its centre.* While, as a red tint had been communicated to the specimen, its reticulations were most easily discerned in the red discs, inasmuch as the tints of all

substances are most brilliant when viewed in light of their own colour.

By way of recapitulation, I shall beg to sum up with the following remarks:—

1. When small bodies are brought very near to the eye, their images are magnified, just as images of larger objects when seen at a distance are diminished, and by the same law.

2. The apparent magnitude of objects depends on their visual angle.

3. The visual angle, for short distances, may be well illustrated by employing a small circular disc of light.

4. A minute circular disc of light is procured by perforating a card with a needle, through which the light is then permitted to pass.

5. A sewing-needle, of the size marked No. 6, produces an aperture about the one-fortieth of an inch in diameter.

6. In order to examine the light which is transmitted through such an aperture, all extraneous rays should be excluded; hence the plane in which the opening is made should be placed at the end of a tube.

7. The pencil of light admitted through an opening of this kind, held within an inch or so of the eye, consists of rapidly-diverging rays falling upon the cornea. Some of these are entirely lost, others are intercepted by the iris, while the remainder pass on through the pupil, which communicates to the image formed on the retina its circular form.

8. Whether the small aperture itself be round or triangular, square or irregular, in form, provided its area do not much exceed that of a circle the one-fortieth of an inch in diameter, its image is always circular.

9. When more than one aperture is used, and these of different tints, secondary colours result from the overlapping and blending of the images of the primary.

10. If the three primary colours, *yellow*, *red*, and *blue* are used, their images which overlap in pairs produce orange, violet, and green light; and when the images of all three blend white light is the result.

11. When a small transparent object is held *close* to the eye it is altogether invisible.

12. But its outline is immediately determined by the light transmitted through one of the small inlets above described, and it is then seen to be not only *magnified* but *inverted*.

13. The image becomes much more distinct when more than one aperture is used, for the intensity of light by which it is illuminated is thereby increased, being almost in a direct ratio with the number of the openings which are employed.

14. The pencils of light which are used for this purpose not only illuminate the object, but intersect in their passage through it, producing as many images as there are apertures.

15. Hence, when a small object is examined by the light admitted through small apertures, it will appear *magnified*, *inverted*, *multiplied*, and illuminated with variable degrees of intensity.

16. The apparent magnitude of an object varies with the distance of the source of light by which it is rendered visible; when this recedes, the pencil of light has less divergence, and the object appears smaller; when, on the other hand, it approaches the eye, the visual cone has a rapid expansion, and the object *still held in the same position* appears magnified.

17. All these effects are demonstrable by using artificially-prepared transparent figures, the dimensions of each of which do not exceed the diameter of the pupillary opening of the eye.

18. It is probable that the minute structure of many natural transparent objects may be recognised in the same way. The hexagonal facets in the eye of the dragon-fly certainly can.

19. These phenomena are, for obvious reasons, but imperfectly discriminated by short-sighted persons.

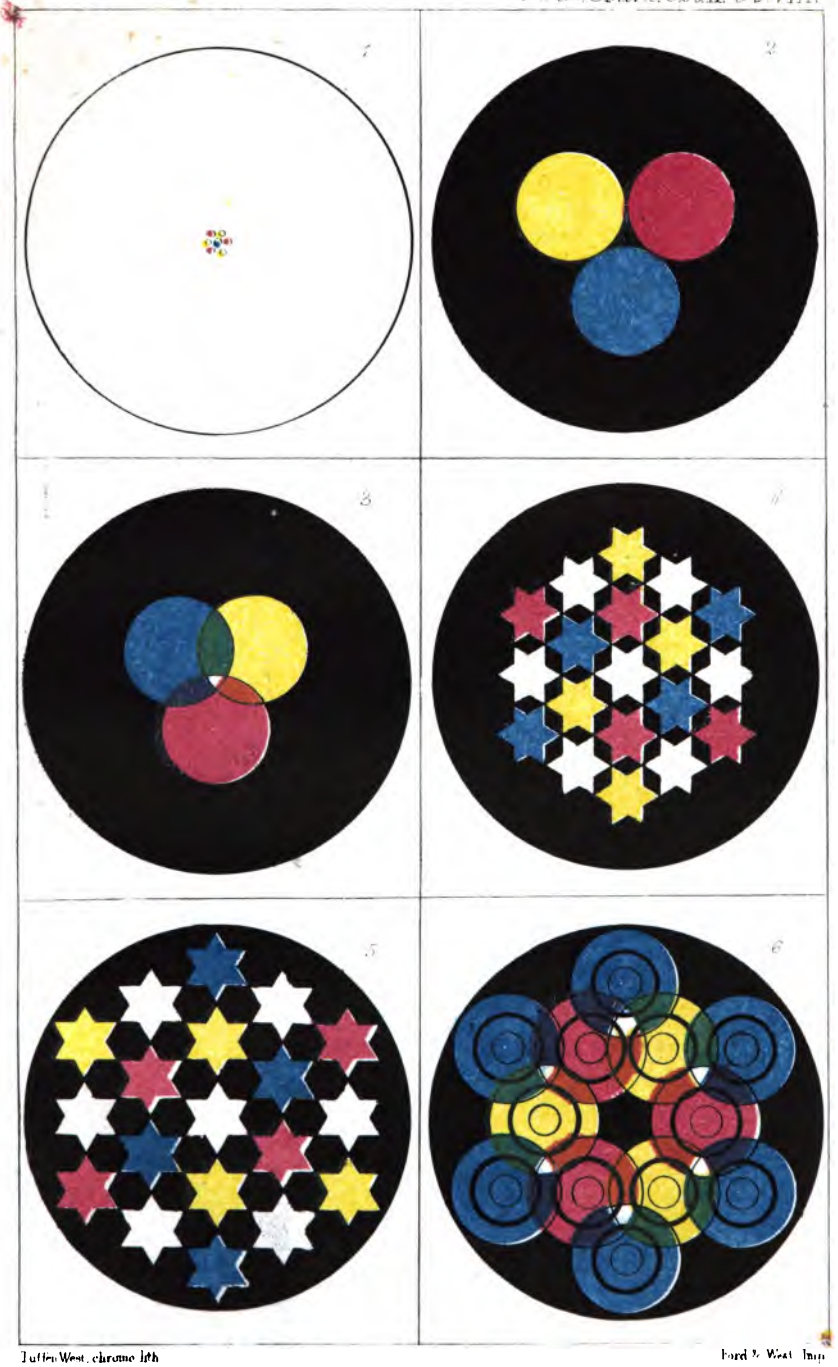
20. And, finally, it should be noticed that the investigations resulting in the phenomena described in these papers were commenced, and have been conducted throughout, for the specific purpose of testing the power of the naked eye in concentrating the rapidly-diverging rays of light, proceeding from bodies when held at very short distances from it unaided by a lens; and from these inquiries it would appear, amongst other results, that the magnifying power of the eye is limited by the magnitude of the visual angle on the one hand, and by the intensity of light on the other. If the visual angle be too large, the rays are not sufficiently refracted by the humours of the eye to converge to a focus, and form an image on the retina; and if too small, the image is reduced to a mere point. The exact amount of divergence of the rays, therefore, for any individual eye lies somewhere between these two extremes. Again, however nicely adjusted the visual angle may be to the refractive powers of the eye, if the light be too strong the pupil becomes so contracted that only the innermost rays are admitted; while, if it be of small intensity, the object is so dimly illuminated as to be scarcely visible. If, then, whilst a small object is held very near to the eye, so as to insure a rapid divergence of the rays proceeding from it, the pupil can be dilated by the small quantity of light which is used, and to which like a photometer it immediately responds, so as

to admit as large an angle as the lenses of the eye are capable of refracting, at the same time that the object is rendered distinctly visible, then, under such circumstances, we have arrived at the utmost limit to the available magnifying power of the eye. These conditions are fulfilled in the *diascope*, which may be defined to be *an instrument which enables us to develop the microscopic power of the eye by retaining an object close in front of it at one end, while it is examined by the light admitted through small apertures at the other.**

With such a simple optical instrument, altogether destitute of glass, a series of images may be presented which have never before been seen with the naked eye; and by its use we are led to a legitimate conclusion capable of direct proof, that when a transparent figure is held very near to the eye for the purpose of magnifying it, if an image is seen at all its size will bear an inverse ratio to the intensity of light by which it is made visible.

In my next communication, which will embody the second part of the subject, I shall beg permission to describe and delineate another set of forms distinct from those which have been noticed in this, and which are produced by substituting straight or circular very narrow apertures of light for the perforations. With such apertures, figures are seen as in perspective, lines appear expanded into planes, and these are multiplied into solids, which, from being of an ethereal brightness, bear a resemblance to models of regular geometric solids of pure glass.

* This instrument may be procured at Mr. Highley's Scientific Library, 32, Fleet-street, London.



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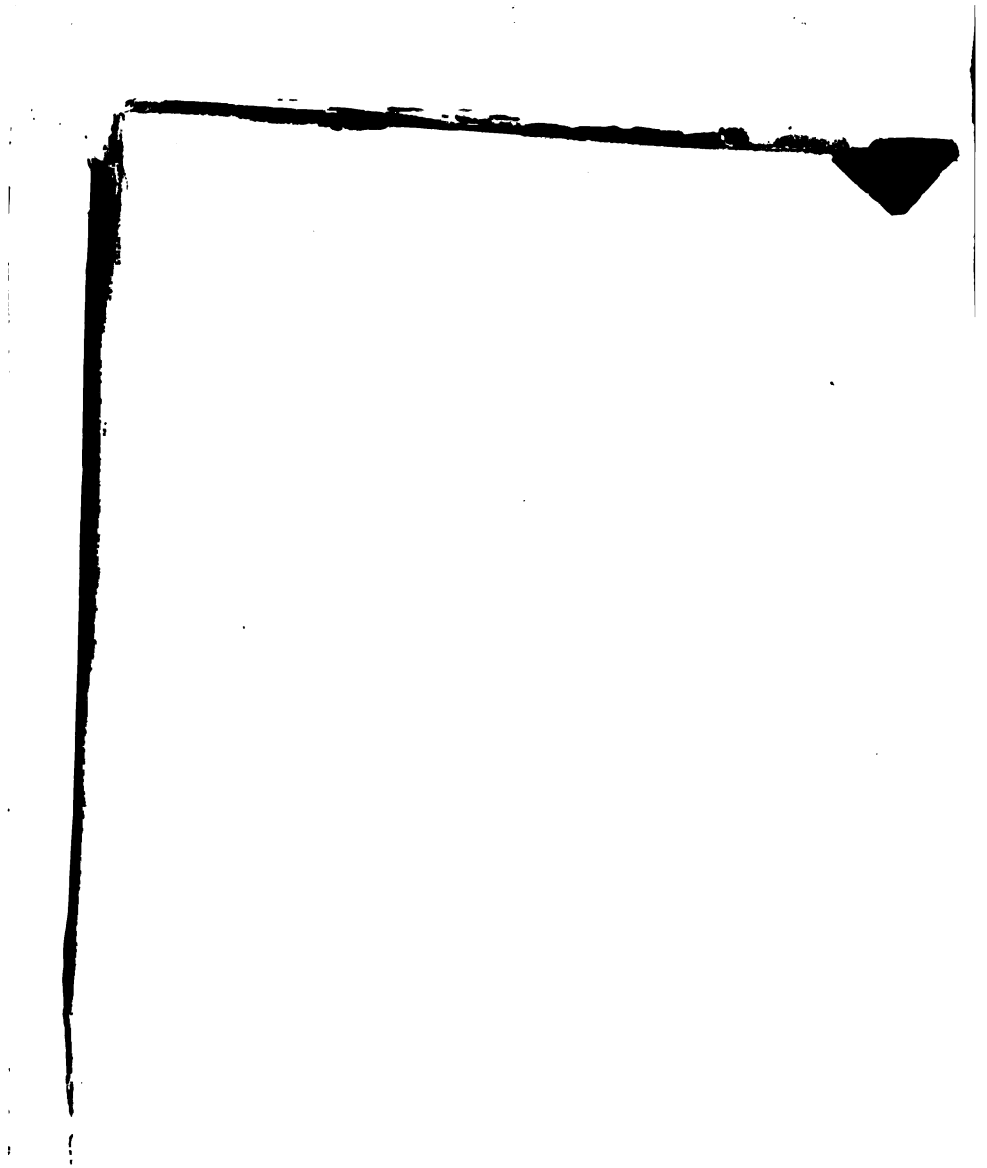

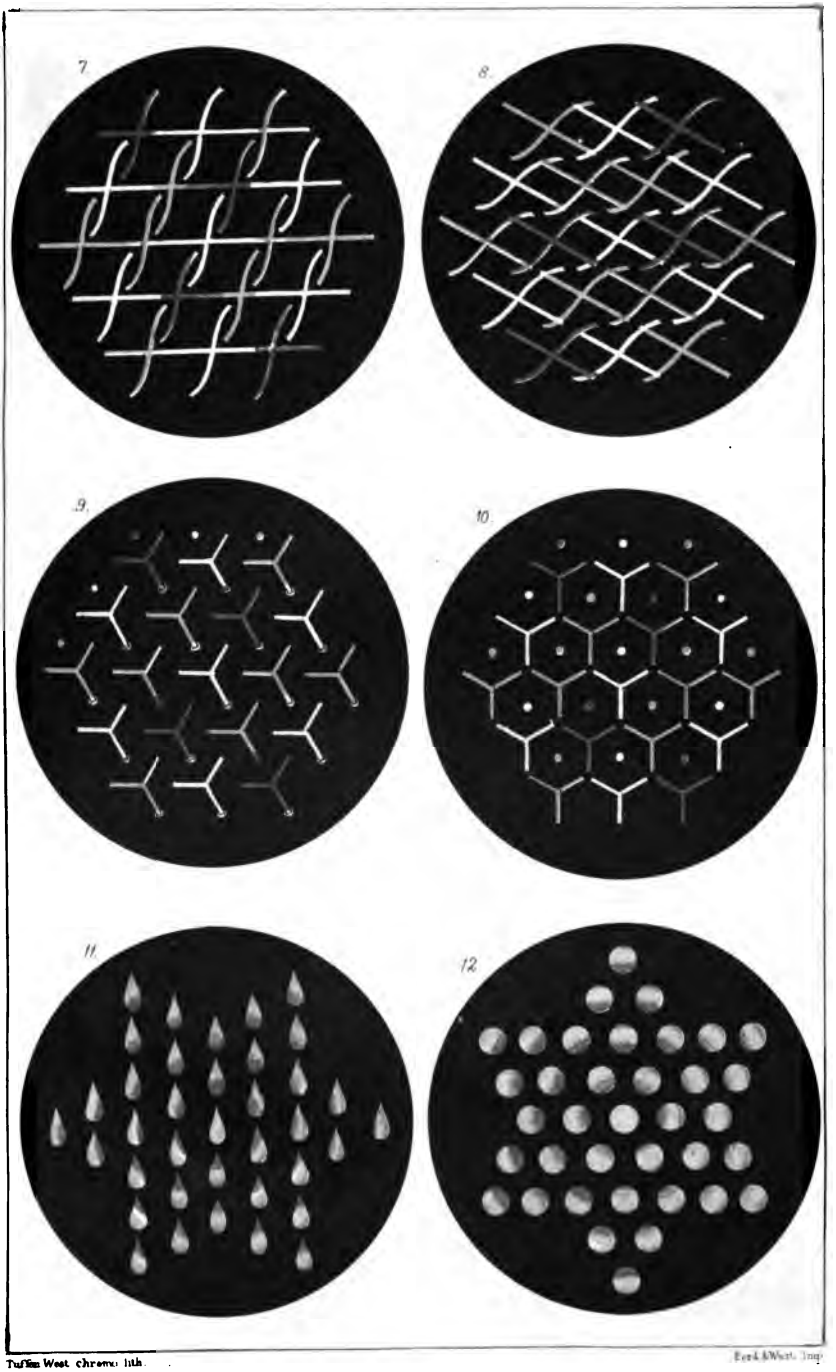

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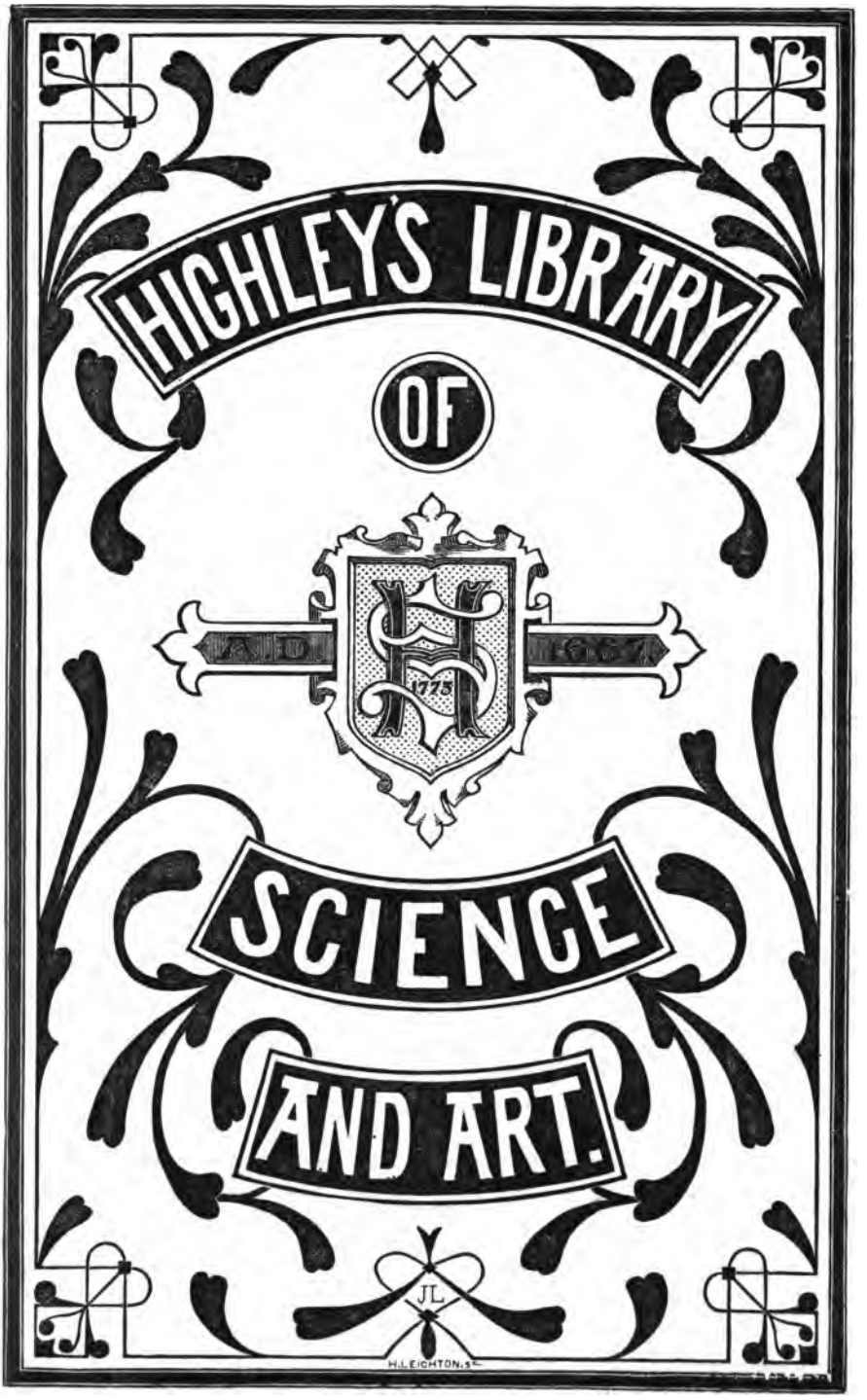
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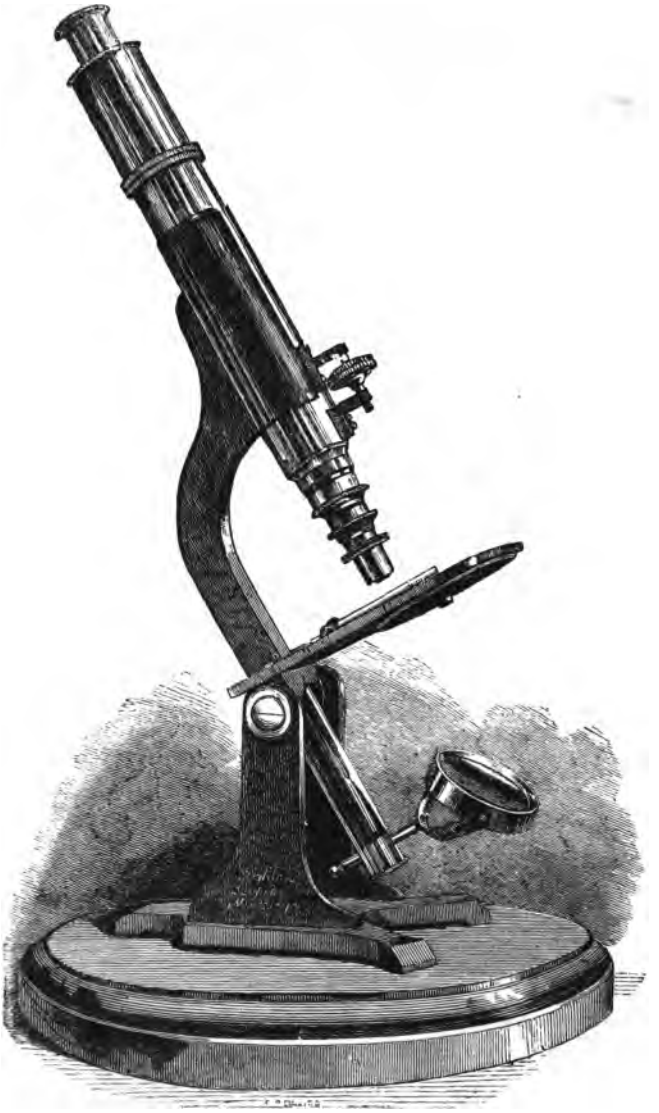

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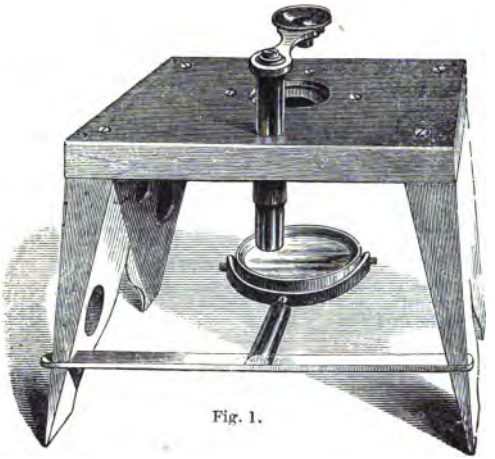

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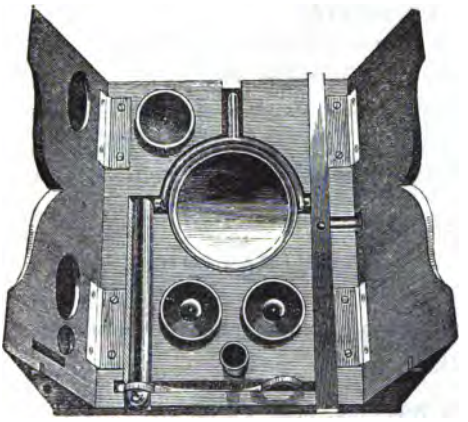

Fig. 2.

Fig. 3.

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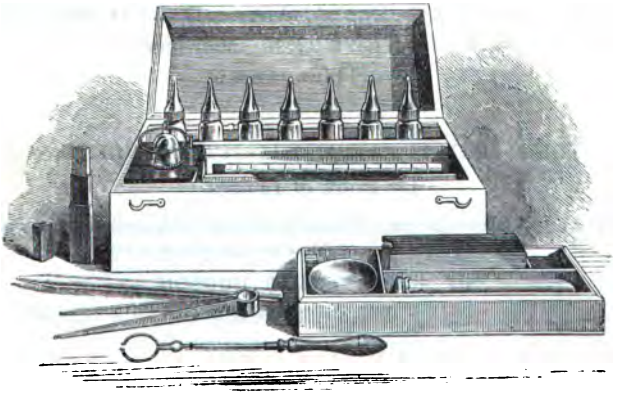

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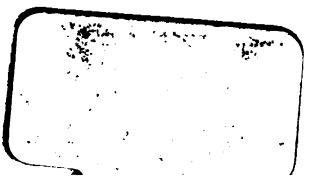

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